PW-PWR/G3

Standalone Solar PV Systems Guidelines

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1 Purpose

This document provides minimum technical requirements, for the design, installation, safety, and operation and maintenance of standalone solar PV Systems used for the supply of low voltage electric power.

2 Scope

This document applies for Kahramaa projects as well as for projects that belong to private users. This document also covers quality assurance technical characteristics for equipment used in the Standalone PV Systems. The standard specifications mentioned in this document shall be followed by the qualified Consultants / Contractors involved in the design, construction, testing, and operation and maintenance of standalone solar PV Systems.

The scope of this document encompasses the standalone solar PV Systems, which are solar-electric generation systems supplying power to a load(s) **but are not connected to Kahramaa's electricity distribution grid**.

The requirements in this document cover the following components: PV Modules (and PV Arrays), mounting systems, power conversion equipment (Inverters and Charge Controllers), batteries, and Balance of System components (wiring, DC Combiner Box, etc.).

This document applies to:

- Projects developed for Kahramaa.
- Systems powered by one or several PV Modules, with a nominal peak power from 100 Wp up to the peak power required to supply the user's loads connected to the Off-Grid System.

2.1 Application

This document shall be read in conjunction with any relevant standards or codes in the State of Qatar that relate to electrical installations, electrical safety, mechanical and civil works, and any other aspects related to standalone solar PV Systems. All standalone solar PV Systems shall comply with the latest version of Kahramaa's Electricity Wiring Code 2016 to the extent applicable. All equipment used in these systems shall fulfil the requirements of the relevant International Standards mentioned in the Section "Key References" and recalled as appropriate in the document, and comply with the quality, health, and safety requirements of the relevant authorities in the State of Qatar.

The standalone PV Systems shall comply with the specifications listed in this document, according to the component they apply to. This ensures that components and equipment of the standalone PV Systems fit with a minimum set of technical characteristics that give the necessary quality. Further, since some international standards may be subject to future revisions, amendments, or extensions, the Consultants / Contractors of the Consumers are requested to use to the latest published versions.

3 Abbreviations, Definitions of Terms & Key References

Abbreviations

AC	:	Alternating Current	AFCI	:	Arc Fault Circuit Interrupter
ASTM	:	American Society for Testing and Materials	BAPV	:	Building-Attached Photovoltaic Modules
BIPV	:	Building-Integrated Photovoltaic modules	$\cos\varphi$	:	Power factor
DC	:	Direct Current	GHI	:	Global horizontal irradiance
IEC	:	International Electrotechnical Commission	IP	:	Interface Protection
IR	:	Infrared	ISO	:	International Organization for Standardisation
ITP	:	Inspection and Test Plan	LOM	:	Loss of Mains
LV	:	Low Voltage (namely 220/127 V or 380/220 V or 400/230 V)	LVRT	:	Low Voltage Ride Through
MV	:	Medium Voltage (namely 13.8kV or 33 kV)	MS	:	Method Statement
NEC	:	National Electrical Code	NFPA	:	National Fire Protection Association
P	:	Active power	P_{ELV}	:	Protected Extra Low Voltage
P_{nom}	:	Nominal active power of the equipment	POA	:	Plane of Array
PPE	:	Personal protective equipment	PR	:	Performance Ratio
PV	:	(Solar) Photovoltaic	Q	:	Reactive Power
RCD	:	Residual Current Device	ROCOF	:	Rate of Change of Frequency expressed in Hz/s.
S/S_n	:	Apparent Power	SELV	:	Safety extra-low voltage
SPD	:	Surge Protection Device	SR	:	Soiling Ratio
STC	:	Standard Test Condition	UL	:	Underwriters Laboratories
UV	:	Ultraviolet	V_{nom}	:	Nominal Voltage
WMO	:	World Meteorological Organization	PW	:	Planning & Development Production Water Resource Dept

Term	Description
AC Module	PV Module with an integrated Inverter in which the electrical terminals are AC only
Active Power	Active Power is the real component of the apparent power, expressed in watts or multiples thereof, e.g., kilowatts (kW) or megawatts (MW). In the text, this will be generically referred as *P* or P_{nom} in case of the nominal active power of equipment
Apparent Power	The product of voltage and current at the fundamental frequency, and the square root of three in the case of three-phase systems, usually expressed

Term	Description
	in kilovolt-amperes (kVA) or megavolt-amperes (MVA). It consists of a real component (Active Power) and the reactive component (Reactive Power). This will be generically referred to *S* or S_n in case of the rated apparent power of equipment
Apparent power of an Inverter	The rated apparent power of an Inverter is the product of the rms voltage and current and is expressed in kVA or MVA.
Auxiliary Supply Power	Electricity supply for supporting auxiliary systems and services such as Interface Protection or circuit breaker and contactor opening coils.
Building-Attached Photovoltaic Modules (BAPV Modules)	Photovoltaic modules are considered to be building-attached if the PV Modules are mounted on a building envelope. The integrity of the building functionality is independent of the existence of a building-attached photovoltaic module.
Building Attached Photovoltaic system (BAPV System)	Photovoltaic systems are considered to be building attached if the PV Modules they utilise do not fulfil the criteria for BIPV Modules.
Building-Integrated Photovoltaic modules (BIPV Modules)	Photovoltaic modules are considered to be building-integrated if the PV Modules form a construction product providing a function. Thus, the BIPV Module is a prerequisite for the integrity of the building's functionality. If the integrated PV Module is dismounted (in the case of structurally bonded modules, dismounting includes the adjacent construction product), the PV Module would have to be replaced by an appropriate construction product. The building's functions in the context of BIPV are one or more of the following: • mechanical rigidity or structural integrity • primary weather impact protection: rain, snow, wind, hail • energy economy, such as shading, daylighting, thermal insulation • fire protection • noise protection • separation between indoor and outdoor environments • security, shelter or safety Inherent electro-technical properties of PV, such as antenna function, power generation and electromagnetic shielding etc., alone do not qualify PV Modules to be building-integrated.
Building-Integrated Photovoltaic system (BIPV System)	Photovoltaic systems are considered to be building-integrated if the used PV Modules fulfil the criteria for BIPV Modules.
Circuit Breaker (CB)	As per the Kahramaa Electricity and Wiring Code definition
Connection Point	Also referred to as *Point of Connection*, is the interface point at which a PV System of the Consumer is connected.
Consultant	A qualified consultant for the design of grid-connected solar PV Systems.
Consumer	Any Person supplied with electricity services for his own consumption. In this context, this term will also be used to refer to a User owning a solar PV System.
Contractor	A certified contractor for the installation of grid-connected solar PV Systems.
Delay time (of a protection relay)	Indicates the minimum duration of a fault detected by the protection relay before the output of the protection relay is triggered.
Delivery Point	The interface point at which electrical energy is delivered by Kahramaa to a Demand Facility or Generating Unit or by a Demand Facility or Generating Unit to Kahramaa.

Term	Description
Distribution System / Distribution Network	Qatar electrical infrastructure (lines, cables, substations, etc.) at 33 kV and below, operated by Kahramaa. The Distribution network can be either a Medium or Low Voltage system for the scope of the present document and in accordance with international standards: • A Low Voltage (LV) Distribution System is a network with a nominal voltage lower than 1 kV AC or 1.5 kV DC. The LV network in the State of Qatar is 240/415 V ± 6%, 3 Phase, 4 Wire. • A Medium Voltage (MV) Distribution System is a network with nominal voltage included in the range from 1 kV AC up to 33 kV. The MV Distribution System nominal voltages in Qatar are 11, 22 and 33 kV. • Electrical network voltages equal to or higher than 33 kV are not considered in this document. According to the Transmission Grid Code, the 33 kV is considered a sub-transmission network. To avoid doubt, the term Distribution Network will be preferred in this document in place of Distribution System.
Electricity Transmission Network (ETN)	Qatar electrical infrastructure (lines, cables, substations, etc.) from above 33 kV up to 400 kV operated by Kahramaa.
Global horizontal irradiance (GHI)	Direct and diffuse irradiance incident on a horizontal surface expressed in W/m^2.
In-plane irradiance (Gi or POA)	The sum of direct, diffuse, and ground-reflected irradiance incidents upon an inclined surface parallel to the plane of the modules in the PV Array, also known as plane-of-array (POA) irradiance. It is expressed in W/m^2
$I_{MOD\_MAX\_OCPR}$	PV Module maximum overcurrent protection rating determined by IEC 61730-2 (Note: This is often specified by module manufacturers as the maximum series fuse rating).
Inspection	Examination of an electrical installation in order to ascertain correct selection, design and proper erection of electrical equipment.
Interface protection (IP)	Electrical protection part of the solar PV System that ensures the PV System is disconnected from the network in case of an event that compromises the integrity of Kahramaa’s distribution network.
Inverter	Electric energy converter that changes direct electric current to single-phase or polyphase alternating current.
Irradiance (G)	Incident flux of radiant power per unit area expressed in W/m^2.
Irradiation (H)	Irradiance integrated over a given time interval and measured in energy units (e.g., $kWh/m^2/day$).
Islanding	Situation where a portion of the distribution network containing generating plants becomes physically disconnected from the rest of the distribution network. One or more generating plants maintain electricity supply to such isolated parts of the distribution network.
Load Flow	It is a numerical analysis of the electric power flow in a transmission and/or distribution systems. A power-flow study usually uses simplified notations such as a one-line diagram and per-unit system, and focuses on various parameters, such as voltages, voltage angles, real power and reactive power. It analyses the power systems in normal steady-state operation.
Loss Of Mains (LOM)	Represents an operating condition in which a distribution network, or part of it, is separated from the main power system (on purpose or in case of a fault) with the final aim of de-energisation. The protection that detects this condition is known as anti-islanding protection.

Term	Description
Main Meter	It is the bidirectional smart meter installed at the Connection Point which measures the amount of electric energy actually exchanged (import or export) by the Consumer with the distribution network.
Maximum Available Active Power Output	This is the Active Power Output based on the primary resource (for example, sun irradiance) and the maximum steady-state efficiency of the Solar PV System for this operating point.
Maximum Capacity (P_{max})	It is the maximum continuous active power which a Generating Unit can produce, less any auxiliary consumption associated used to facilitate the operation of that Generating Unit. The Maximum Capacity shall not be fed into the distribution network as specified in the *Connection Agreement*. In this document, this term is also referred to as Maximum Connected Capacity.
Micro-Inverter	Small Inverter designed to be connected directly to one or two PV Modules (Note: A micro Inverter will normally connect directly to the factory fitted module leads and be fixed to the module frame or mounted immediately adjacent the module).
Module Integrated Electronics	Any electronic device fitted to a PV Module that provides control, monitoring or power conversion functions (Note: Module integrated electronics may be factory fitted or assembled on-site).
National Control Centre (NCC)	Main Kahramaa's facility used to operate and control/maintain the Electric Power System.
Peak Power (Wp)	The output power achieved by a Photovoltaic Module under Standard Test Conditions (STC). It is measured in W_p (W peak). The sum of the peak power of the photovoltaic modules of either a string or an array determines the peak power of the string and the array, respectively (usually measured in kW_p). The peak power of a photovoltaic array at STC is conventionally assumed as the rated power of the array.
Photovoltaic (PV) cell	The most elementary device that exhibits the photovoltaic effect, i.e., the direct non-thermal conversion of radiant energy into electrical energy.
Power Factor	It is the ratio of Active Power to Apparent Power.
Power Park Module (PPM)	A unit or ensemble of units generating electricity, which is either non-synchronously connected to the network or connected through power electronics, and that also has a single Connection Point to the ETN.
PV Array	Assembly of electrically interconnected PV Modules, PV strings or PV sub-arrays. For the purposes of this document, a PV Array comprises all components up to the DC input terminals of the Inverter.
PV Module	PV Modules are electrically connected PV cells packaged to protect them from the environment and protect the users from electrical shock.
PV String	A set of series-connected PV Modules.
PV String Combiner Box	A box where PV strings are connected, which may also include circuit breaker, monitoring equipment, and electrical protection devices.
Rated Active Power	Represents the sum of the nominal active power of all the Solar PV Units which compose the Solar PV System; it is generally referred to as *Pnom* of the Solar PV System.
Reactive Power	Represents a component of the apparent power at the fundamental frequency, usually expressed in kilovar (kVAr) or Megavar (MVAr).
Reactive Power Capability	Defines the reserves of inductive/capacitive reactive power which can be provided by a generating system/unit. The reactive power capability usually varies with the active power and the voltage of the generating system/unit.

Term	Description
Residual Current Device (RCD)	A sensitive switch that disconnects a circuit when the residual current exceeds the operating value of the circuit, referred as RCD in this document.
Soiling ratio (SR)	A ratio of the actual power output of the PV Array under given soiling conditions to the power that would be expected if the PV Array were clean and free of soiling.
Solar PV System	This term also has the same meaning as Power Plant or User's System or Grid User, defined in the Transmission Grid Code. It is a solar PV installation of not more than 25 MW and not less than 1 kW capacity installed in one Premise and connected in parallel to Kahramaa's Distribution Network. This document aims to be considered a power plant with one or more Solar PV Units. Besides, circuits and auxiliary services are also part of a solar PV System. To avoid doubt, in this document, the generic term Solar PV System is considered equivalent to solar PV System. This PV System includes the PV Array, controllers, Inverters, batteries (if used), wiring, junction boxes, circuit breakers, and electrical safety equipment.
Solar PV System Meter	It is the smart metering installed at the output point of the solar PV System and measures the total energy produced from the Solar PV Units.
Solar PV Unit	A group of devices that collects the sun's irradiance in a Solar PV System, together with all plant and apparatus and any step-up transformer which relates exclusively to the operation of that part of the same Solar PV System. Only units that are Inverter based (i.e., Asynchronously connected to the Distribution Network through power electronics devices) are considered in this document. This definition will be equivalent to that of the Power Park Module as given in the Transmission Code. For the avoidance of doubt, in this document, the generic term Solar PV Unit will be considered equivalent to a solar PV Unit.
Standard test conditions (STC)	Reference values of in-plane irradiance (1 000 W/m2), PV cell junction temperature (25 °C), and the reference spectral irradiance defined in IEC 60904-3.
Switch	As per the Kahramaa Electricity and Wiring Code definition.
Testing	Implementing measures in an electrical installation to prove its effectiveness (Note: It includes ascertaining values using appropriate measuring instruments, said values not being detectable by inspection).
Time Current Curve (TCC)	The time current curve plots the interrupting time of an overcurrent device based on a given current level. These curves are used for the protection coordination and are provided by the manufacturers of electrical overcurrent interrupting devices such as fuses and circuit breakers.
THD (Total Harmonic Distortion)	Concerning an alternating quantity, it represents the ratio of the r.m.s. value of the harmonic content to the r.m.s. value of the fundamental component or the reference fundamental component.

Key References

[1] CS-CSI-P1/C1 Kahramaa's Low Voltage Electricity Wiring Code 2016

[2] EP- EPP-P7/S1 Technical Specifications for the Connection of PV Systems to the Network

[3] EP-EPP-P7/G2 Guidelines for Information in Basic and Final Design, last revision

[4] CS-CSI-P3/G2 Inspection and Testing Guidelines for Solar PV Systems Connected to LV and MV Network, last revision

[5] EP-EPM-G2 Guidelines for the Eligibility of Manufacturers' Equipment, last revision
[6] PW-PWR/G2 Safety related to the installation of Solar PV Systems, last revision

PV Modules

[7] IEC 61215 Part 1, Terrestrial PV Modules - Design qualification and type approval - Test requirements
[8] IEC 61215 Part 1-1/2/3/4, Terrestrial PV Modules - Design qualification and type approval Special requirements
[9] IEC 61215 Part 2, Terrestrial PV Modules - Design qualification and type approval - Test procedures
[10] IEC 61730 Part 1, PV Modules safety qualification - Requirements for construction
[11] IEC 61730 Part 2, PV Modules safety qualification - Requirements for testing
[12] IEC 62790, Junction boxes for photovoltaic modules – Safety requirements and tests

PCE

[13] IEC 62093, PV System power conversion equipment - Design qualification and type approval
[14] IEC 62109 Part 1, Safety of power converters for use in PV power systems - General requirements
[15] IEC 62109 Part 1, Safety of power converters for use in PV power systems - Particular requirements for Inverters
[16] IEC 62509, Battery Charge Controllers for PV Systems - Performance and functioning
[17] IEC TS 63157, PV Systems - Guidelines for effective quality assurance of power conversion equipment
[18] UL1741, Standard for Inverters, Converters, Controllers, and Interconnection System Equipment for use with Distributed Energy Resources
[19] IEC 62920, PV power generating systems - EMC requirements and test methods for power conversion equipment
[20] IEC 60068-2-68, Environmental testing - Part 2-68: Tests - Test L: Dust and sand

Battery Storage

[21] IEC 60896 Part 1, Stationary lead-acid batteries – Vented types - General requirements and methods of tests
[22] IEC 60896 Part 1, Stationary lead-acid batteries – Valve regulated types - Methods of test
[23] IEC 60896 Part 1, Stationary lead-acid batteries - Valve regulated types - Requirements
[24] IEC 61427-1, Secondary cells and batteries for renewable energy storage - General requirements and methods of test - PV off-grid application
[25] IEC 62485, Safety requirements for secondary batteries and battery installations
[26] IEC 62133, Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications
[27] IEEE Std. 1361-2014, IEEE guide for selecting, charging, testing, and evaluating lead-acid batteries used in stand-alone PV Systems

[28] IEEE Std. 937-2019, IEEE recommended practice for installation and maintenance of lead-acid batteries for PV Systems

BOS

[29] IEC 62930, Electric cables for PV Systems with a voltage rating of 1.5 kV DC
[30] IEC 62852, Connectors for DC-application in PV Systems - Safety requirements and tests
[31] IEC 61439 Part 1, Low-voltage switchgear and controlgear assemblies – General rules
[32] IEC 61439 Part 1, Low-voltage switchgear and controlgear assemblies - Power switchgear and controlgear assemblies
[33] UL 2703, Mounting systems, mounting devices, clamping-retention devices, and ground lugs for use with flat-plate PV Modules and panels
[34] IEC 62817, Photovoltaic systems – Design qualification of solar trackers

Design, Commissioning and O&M

[35] IEC 60364 Part 1, Low-voltage electrical installations – Requirements for initial and periodic verification
[36] IEC 60364 Part 1, Low-voltage electrical installations - Requirements for special installations or locations - PV power supply systems
[37] IEC 62124, PV standalone systems - Design verification
[38] IEC 62548, PV Arrays - Design and earthing requirements
[39] IEC 60364-5-54, Earthing for all LV installations
[40] IEC-62305–1/2/3/4, Lightning Protection
[41] IEC TR 63226, Managing fire risk related to PV Systems on buildings
[42] NEC Article 690, Safety standard for installation of Solar PV Systems

Hybrid Systems

[43] IEC 62257, Recommendations for renewable energy and hybrid systems for rural electrification

Solar-Powered Pumping Systems

[44] IEC 62253, PV pumping systems - Design qualification and performance measurements

4 Technical Requirements, Installation, and Safety Guidelines

4.1 Overview

Standalone solar PV Systems are composed of a collection of interconnected electrical components, which can generate electricity from sun-light and satisfy our daily energy requirements in an environmentally friendly way. **Standalone solar PV Systems are those not connected to Kahramaa's distribution grid** and can be connected directly to a single load or to an electrical installation via the distribution board (where all solar generated electricity will be consumed internally).

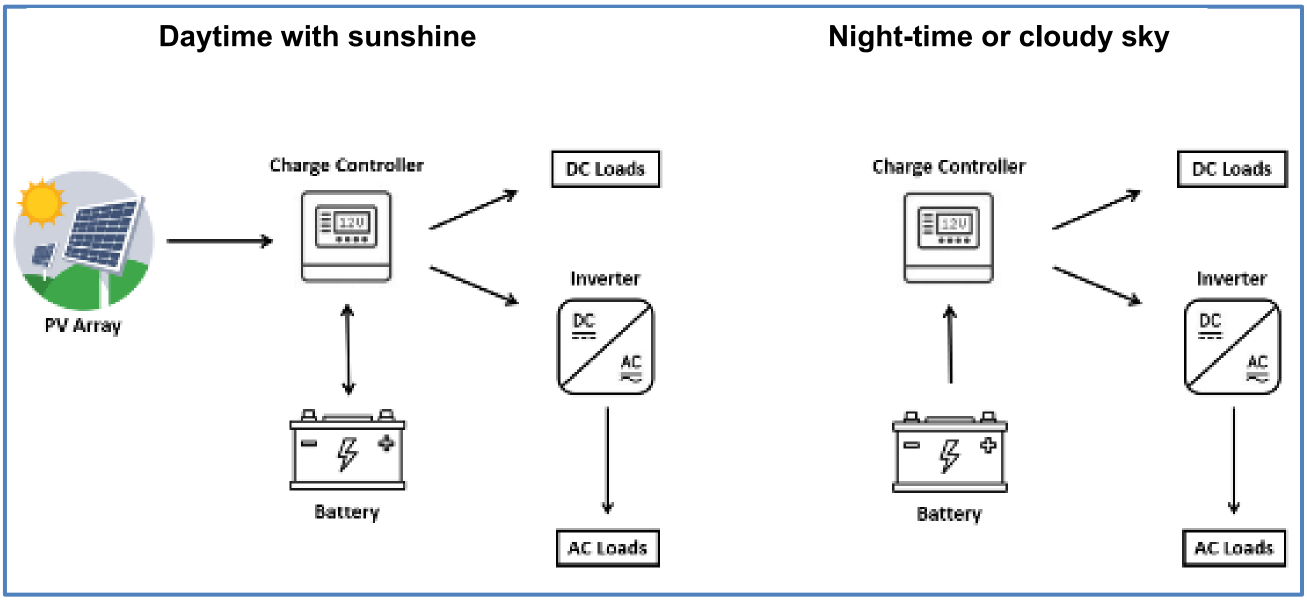

Figure 1 – Schematic of a typical standalone solar PV System. In daytime the PV Modules supply the loads and charge the batteries, at night-time loads receive power from batteries.

Figure 1 shows the concept of a simple standalone PV System that produces electrical power to charge batteries during the day for immediate use or for use at night. A generic single line diagram is presented in Annex B. Standalone PV Systems can be useful in remote sites and applications where other power sources are unavailable to provide power for lighting, appliances, and other uses. In these cases, it is more cost effective to install a single standalone PV System than pay the costs of extending power lines and cables directly to the remote site to connect the PV System to the local network. Batteries are important in any standalone PV System, regardless of its capacity. During sunshine the PV System feeds the load and sends excess energy to the batteries for later use, during the night or when sky is cloudy.

A typical standalone solar PV System consists of a PV Array, PV Array support structure, string/array combiner boxes, DC cabling, DC distribution box, Charge Controller, battery, Inverter, AC cabling, AC distribution box, and system AC energy meter. Some of these components are optional and are not required in some applications (e.g., batteries are not mandatory for solar water pumping systems). The schematic of standalone solar PV System in Figure 1 shows the interconnection of the system components.

More examples of Standalone Solar PV Systems are provided in Annex A.

4.2 General Safety Requirements

The selection and installation of all components in standalone solar PV Systems shall comply with Kahramaa's Electricity Wiring Code 2016 and any other relevant codes or standards in the State of Qatar. All design, installation, and commissioning activities shall be done by Kahramaa approved Consultants and Contractors.

The PV Array and its associated components shall be rated for DC use, have a voltage rating equal to or higher than the PV Array maximum voltage, and be rated for the maximum possible current in the electrical circuit. PV Arrays, Charge Controllers, Inverters, and batteries shall be located as close as possible to each other to reduce DC wiring losses. Batteries shall have proper ventilation and shall be located at an appropriate distance from nearby equipment. Appropriate protection and safety procedures shall be applied for hazards associated with batteries, which include electrical hazards, mechanical hazards, chemical hazards, fire hazards, energy hazards, explosive gas hazards, and toxic fume hazards. The junction box of the PV Modules shall be IP68 rated to protect terminals against dust and water and ensure durable PM module operation in any environmental condition.

The AC output voltage of the standalone solar PV System shall be in accordance with declared voltage in the State of Qatar as stated in clause 1.4 in Kahramaa' s Electricity Wiring Code 2016[1]. The main incomer protection for the distribution board at the AC side of the installation shall have an ELCB (earth-leakage circuit breaker) of appropriate load rating, considering that the neuter-state of an independent energy source may differ from the TT system usually provided by the DSO.

There should be signs that clearly identify the standalone solar PV System components and the possible electric hazards and/or risks. Clear instructions on system shutdown procedure and response required for emergencies shall be provided, alongside any necessary sketches or electric line diagrams. All equipment with moving parts (e.g., PV Trackers) and subject to elevated temperatures (above 70°C) shall be mechanically and thermally protected. Protection against dust and sand for joints and coupling systems is particularly important. All wires shall be protected in accordance with Kahramaa' s Electricity Wiring Code. Batteries shall have overcurrent protection.

All components in the standalone solar PV System exposed to outdoor conditions shall be IP65 rated as a minimum and shall be UV resistant. Enclosures such as combiner and junction boxes and battery storage boxes placed externally without a shelter shall be at least IP65 rated. Conversely, if battery storage boxes are placed in a room or a shelter, an IP65 box may be unfit as it can prevent the natural ventilation: in these cases, a proper protection degree shall be adopted. For specific products using PV Modules and batteries as power source, like lighting posts and surveillance posts equipped with video cameras, a proper mechanical protection (e.g., IK10) can be recommended.

4.3 Requirements for the Equipment and Compliance

The equipment of the Standalone Solar PV Systems shall comply with the requirements specified by the International Standards (IEC, UL, EN, etc.) listed in the present document.

[1] The LV network in the State of Qatar is 240/415 V ± 6%, 3 Phase, 4 Wire.

Manufacturers and vendors shall deliver compliance certificates and test reports along with the supplied equipment. Consultants/Contractors shall verify the supplied documents prior to equipment acceptance and installation.

4.4 System Design Procedures

The design of standalone solar PV Systems shall be done by Kahramaa approved consultant and contractor and in accordance with applicable International Standards and practices. The final system design shall be robust, meet the user requirements, optimize components, ensure safe system operation, and comply with local standards and regulations. The following factors should be carefully considered in the design process:

- The system autonomy should be chosen to suit the load characteristics and the local weather conditions.
- The PV Array positioning (azimuth angle and tilt angle) should be decided based on computer simulations by the system integrator.
- The following paragraphs provide general requirements useful for the designing of the components of the standalone solar PV System. Particularly, the competent persons shall ensure that all components comply with International Standards listed in Paragraph 1.3.

4.5 Solar PV Array

4.5.1 PV Modules

4.5.1.1 General Requirements

- PV Modules to be used shall be reliable modules with a proven track record in performance and operation from an established manufacturer.
- PV Modules shall comply with IEC 61215-1,2 and IEC 61730-1,2. Junction boxes shall comply with IEC 62790.
- PV Modules shall only be used in applications corresponding to their declared class rating according to IEC 61215-1/2, IEC 61730-1/2 and other standards applicable.
- Only PV Modules of class II as described in IEC 61730-1 shall be used.
- PV Modules installed in coastal areas shall comply with IEC 61701 for salt mist corrosion.
- The PV Modules supplied for a standalone system shall be of the same type and from a single manufacturer, provided this does not conflict with specific client's purposes. The Contractor shall be responsible for modules' arrangement to minimize the losses due to mismatching and maintain maximum power. Moreover, the quality of equipment supplied shall be generally controlled to meet the guidelines for engineering design included in the standards and codes listed in the relevant IEC and other standards. These guidelines recommend the purchase of PV Modules of the latest technology to maximize conversion efficiency and minimize space occupation, especially in case of space limitations.
- PV Arrays with nominal output voltages greater than 50 V DC shall have bypass diodes unless the manufacturer doesn't require them or if shading is not possible due to the design or the location characteristics.

- All transportation, storage, handling, and installation of the modules shall be done in accordance with the manufacturer specifications, to not to void the module manufacturer's warranty.

4.5.1.2 Identification and Traceability

Each PV Module must use a Radio Frequency Identification Tag (RFID), which must contain essential information about the module. The RFID shall be inside the module's laminate, to be able to withstand harsh environmental conditions. The RFID tag shall contain:

- Name of the manufacturer
- Name of the manufacturer of solar cells
- Unique serial number and model no of module
- Month and year of the manufacture (separately for solar cells and module)
- Country of origin (separately for solar cells and module)
- I-V curve and Nominal Operating Cell Temperature (NOCT) for the module
- Peak power (P_{mp}), maximum power current (I_{mp}), and maximum power voltage (V_{mp})
- Date of obtaining IEC PV Module qualification certificate
- Name of the test lab issuing IEC certificate
- Other relevant information on traceability of solar cells and modules as per ISO 9000 series

4.5.1.3 PV Module's Technical Requirements

The following table shows Kahramaa' s minimum technical requirements for PV Modules for PV Arrays. For systems like street lighting the equipment can consist of a single PV Module of lower size/capacity, whose rated power will depend on the power of the lamp.

Table 1 – PV Module Technical Requirements

No	Parameter	Requirement
Characteristics		
1	PV technology	Crystalline silicon (mono or poly)
2	Suggested rated power	≥ 240 Wp
3	Module efficiency	≥ 15%
4	Temperature coefficient on Pmp	≤ -0.45%/°C
5	Nominal power tolerance from module manufacturer (used for acceptance of modules)	3%
6	System voltage	≥ 1000 V DC
Product warranty and performance guarantee		
7	Workmanship/product replacement	Minimum 10 years
8	Power output guaranteed during the first year of operation	Minimum 97%
9	Degradation until year 25	Linear

No	Parameter	Requirement
10	Linear degradation coefficient from year 2 to year 25	Maximum 0.7%/year
11	Guaranteed output of the nominal power after 10 years	Minimum 90%
12	Guaranteed output of the nominal power after 25 years	Minimum 80%
13	Product warranty against manufacturing defects	Minimum 10 years
14	Wind load rating1	Minimum 2400 Pa
Module and factory certifications		
15	Module certifications	IEC 61215-1,2:2021 IEC 61730-1,2:2016 IEC 62790 (Junction box) IEC 61701:2020 (for coastal installations) IEC 60068-2-68:1994
16	Manufacturer certifications	ISO9001: 2015 ISO14001: 2015 ISO 45001:2018

[1] Please note this is available in PV Module datasheet as "maximum load rating" or "maximum static load".

4.5.1.4 Array Mounting Structure Requirements

- The array mounting structure should comply with UL 2703 standard for safety. Additionally, reference shall be made to IEC 62187 standard when mounting is based on tracking system, outdoor electronic/electrical parts shall be minimum IP65.
- Modules shall be mounted on a corrosion-resistant support structure made of suitable materials capable of maintaining structural integrity, particularly of withstanding the loads that are typical of the installation site.
- The array structure shall be designed to occupy minimum space without sacrificing the output from PV Modules due to shadowing, orientation, or tilt at the same time. However, the space occupation may vary depending on the type of installation, i.e., ground mounted, roof top, park shade, canopy, greenhouse.
- Support structural material shall be corrosion resistant and electrolytically compatible with the materials used in the module frame, its fasteners, nuts and bolts, and mounting clamps should be stainless steel. The support structure shall be free from corrosion when installed.
- Adequate spacing shall be provided between two module frames and rows of modules to facilitate personnel protection, ease of installation, replacement, cleaning of modules and electrical maintenance.
- Minimum clearance between lower edge of PV Module and ground/roof top ground level to allow ventilation for cooling, also ease of cleaning and maintenance of modules as well as cleaning of ground/roof top. Minimum clearance on roof top shall be 50mm to ensure suitable rear cooling through natural ventilation.
- The PV Module mounting structure shall have a capacity to withstand a suitable wind velocity.
- Sufficient gap needs to be provided between following rows to avoid falling of shadow of one row on the next row.

- if installed on roof, then installation of structure for solar PV mounting should not tamper with the water proofing of the roof.
- The supplier shall specify installation details of the PV Modules and the support structures with appropriate diagrams and drawings. Such details shall include, but are not limited to, the following:
  - Determination of true south at the site
  - Array tilt angle to the horizontal, with permitted tolerance
  - Detailed drawings for fixing the modules
  - Detailed drawing for fixing the junction/terminal boxes
  - Interconnection details inside the junction/terminal boxes
  - Structure installation details and drawings
  - Electrical grounding (earthing)
  - Inter-module/Inter-row distances with allowed tolerances
  - Safety precautions to be taken
  - Lightning protection and surge protection systems

The technical characteristics for the PV Array mounting are given in the following table.

Table 2 – Technical Requirements for Array Mounting Structures

No	Parameter	Requirement
1	Installation method	Fixed installation or tracking system
2	Module installation	Portrait or landscape orientation. Must respect row-to-row shadowing and cell (and bypass diode) connections of the PV Module
3	Row to row distance	Minimum distance of 0.5 m between the back of one row and the front of the next row to allow O&M service
4	Distance to parapet	Minimum distance of 2 m (where applicable)
5	Fixation onto the ground (if used)	Using concrete pile or raft foundations
6	Fixation onto the roof (if used)	Via ballast, no penetration of the roof, with no impact on waterproofing of the roof structure
7	Lifetime	≥ 25 years
8	Warranty	≥ 10 years
9	Standard for safety	UL 2703
10	Workmanship warranty	Minimum 10 years
11	Installation warranty	Minimum 10 years

4.6 Power Conversion Equipment (PCE)

Power conversion equipment (PCE) are electric energy conversion devices such as DC/AC Inverters and Battery Charge Controllers. PCE in standalone solar PV Systems optimize PV Array performance and (for systems with batteries) provide optimal battery charging while protecting the batteries from overcharging.

All PCE shall comply with IEC 62109, IEC62093 and safety specifications shall comply with UL 1741.

CE certification for low voltage directive (EN 50178: 1997) is recommended.

4.6.1 Inverter

The solar Inverter converts DC electrical energy generated by PV Arrays (which may then be stored in a battery) into AC electrical energy.

- Inverters shall comply with IEC 62109, IEC 62093, and the safety specifications of UL 1741.
- Inverters to be used shall be reliable Inverters with a proven track record in performance and operation. The manufacturer shall be established in the market.
- The Inverters characteristics shall be selected with respect to the local climatic and environmental conditions, especially regarding temperature, dust, and humidity.
- The Inverter output can be single-phase (220-240 V AC) or three-phase (380-415 V AC), 50 Hz, standard tolerance level.
- The Inverter shall incorporate suitable DC/AC fuses/circuit breakers and a surge protective device. Fuses used in the DC circuit shall be DC rated.
- The Inverter shall have internal protection against any sustained faults and/or lightning in DC
- The kVA ratings of Inverters for the PV Systems should be chosen as per the PV System wattage and should not be less than the total power rating of the loads that are active and need supply during the day.
- in case of outdoor installation, the Inverter enclosure shall be at least IP65 and capable of surviving climatic changes and should keep the Inverter intact under all conditions. The Inverter enclosure shall be at least IP20 if housed in a room, or higher where needed. Moisture condensation and entry of rodents and insects in the Inverter enclosure shall be always prevented.
- The Inverter for standalone PV Systems shall be equipped with proper electronic protections and other functions based on application and/or client's requirements. The following list includes protections and functions these types of Inverters shall provide; Consultant/Contractor may crosscheck the following list and the datasheets to assess the appropriateness of candidate Inverters.

Protections

a) Overcharge protection
b) Reverse polarity protection both for PV Array and Battery bank (DC).
c) Deep discharge protection
d) Short circuit protection of load and module
e) Reverse current protection at night.
f) Overtemperature and overload protection.
g) Protective earthing (PE) protection
h) Battery Low Alarm/cut-off
i) Acoustic alarms of Inverter and Battery.

Additional Functions

a) Auto/Manual reconnects provision.
b) Digital Display(s) of DC input (Solar PV) voltage/current, capacity.
c) Digital Display (s) of AC output voltage/current, frequency, power.
d) Digital Display of AC output kWh meter (Daily/ Cumulative)
e) Battery voltage/current.
f) Solar PV charging.
g) Battery Charge Level LED Indicator (s).
h) LED indicator to indicate the operational status (solar panel or battery).

Table 3 – Technical Requirements for Inverters for Standalone Solar PV Systems with built-in Battery Charge Controller

No	Parameter	Requirement
Inverter Characteristics		
1	Inverter type	Pure sine wave standalone
2	Maximum efficiency sine wave	≥ 94%
3	Maximum efficiency Charge Controller	≥ 97%
4	Operating temperature range	-5 °C to 55°C
DC input – PV Modules		
5	Maximum DC voltage	Compatible with the PV Array
6	MPPT voltage / power	Compatible with the PV Array
Battery side		
7	Maximum Battery Voltage	Depending on system power
8	Battery type	Lead or Li Ion
AC Output		
9	Connection phases	Single/Three-Phase
10	Frequency	50Hz
Protections		
12	Reverse polarity protection	PV Module, load, and battery
13	Short circuit protection	PV Module, load
14	PV Module input overvoltage protection	Required
15	Reverse current protection at night	Required
16	Overtemperature and overload protection	Required
17	Load disconnection on battery overvoltage	Required
18	Surge protection	Required
19	Minimum IP rating for enclosure	IP65 (outdoor) / IP20 (indoor)
Certifications and Warranties		
20	Quality and safety certifications	IEC 62109, IEC 62093, UL 1741
21	Product warranty	≥ 5 years
22	Product replacement warranty	Minimum 5 years
23	Service warranty	Minimum 25 years

Certain applications like street lighting or remote surveillance need PV Module and battery only. However, when both power conversion and storage are needed, the actual equipment characteristics will depend on application and/or client's requirements, eventually reflected in the system specifications. In general, we can consider the following approaches.

- systems that integrate power conversion and battery charging in a single equipment,
- systems with more equipment providing specific functions for power conversion and battery charging. These systems need accurate design and selection of the appropriate equipment, especially when the equipment is selected from several manufacturers.

The minimum technical requirements of the Inverter are given in the following tables.

Table 4 – Technical Requirements of Solar PV Inverter (without Battery Charge Controller)

No	Parameter	Requirement
Inverter Characteristics		
1	Inverter type	Grid-tied
2	Maximum conversion efficiency	≥ 97%
3	European efficiency	≥ 97%
4	Operating temperature range	-5 °C to 55 °C
DC input – PV Modules		
5	Maximum DC voltage	Compatible with the PV Array
6	MPPT voltage / power	Compatible with the PV Array
AC Output		
6	Connection phases	Single/Three-Phase
7	Frequency	50 Hz
8	Total harmonic distortion	≤ 3%
9	Maximal current ripple	3% PP
10	Power factor	Compatible with the loads
11	Overcharging capacity	Compatible with the loads
Protections		
13	String failure detection	Required
14	DC overvoltage protection	Required
15	Surge protection	Required
12	Minimum IP rating for enclosure	IP65 (outdoor) / IP20 (indoor)
Certifications and Warranties		
16	Quality and safety certifications	IEC 62109, IEC 62093, UL 1741
17	Product warranty	≥ 5 years
18	Product replacement warranty	Minimum 5 years
19	Service warranty	Minimum 25 years

Table 3 provides the requirements of an integrated Inverter with battery charging. Table 4 provides the characteristics of an Inverter as similar as the Inverter of the grid-connected systems: this type of Inverter needs additional equipment to implement battery charging as well as any other functions needed to operate a standalone system.

Table 3 shows that nowadays all-in-one Inverters are available that include all the functions needed to operate a standalone system, including a built-in Battery Charge Controller. Instead Table 4 recalls parameters common to Inverters used in grid-tied systems: to operate in standalone PV Systems, these Inverters need further equipment, for instance the Battery Charge Controller described in the next paragraph.

4.6.2 Battery Charge Controller

Battery Charge Controllers shall be used to control the battery charging process from the PV Array, which complies with the requirements of the battery manufacturer, to ensure the maximum life of the batteries.

- A MPPT interface with the PV Array is recommended.
- PCE used as Battery Charge Controllers shall comply with IEC 62509.
- The Charge Controller shall be compatible with the PV Array and batteries being used in terms of rated current and voltage respectively.
- Efficiency of the PV Charge Controller should not be less than 80%.
- The PV Charge Controller shall be rated for at least 125% of the full rated current.
- The PV Charge Controller shall also provide reverse polarity protection for both battery and PV connection, over voltage protection and under voltage cut off.
- PCE ingress protection rating shall comply with IEC 62093.
- The Charge Controller should have easy-to-read indicators illustrating the battery's state of charge, including a light indicator that shows when the battery is fully charged and a series of light indicators to indicate the level of charge.
- Temperature compensation should adjust the charging current to the battery against varying ambient conditions.
- The workmanship warranty of the solar Charge Controller shall be 5 years minimum.
- The Charge Controller must protect against:
  - Short circuits in the charge terminal
  - Transient waves of voltage induced by atmospheric discharges (lightning)
  - Polarity reversal in the module's terminal

4.7 Battery and Energy Storage

4.7.1 General Requirements

- The batteries shall be solar PV batteries of the following types: deep cycle lead-acid and made of hard rubber container or Lithium-ion batteries.
- Batteries shall comply with IEC 61427-1, IEC 60896-11,21,22 (Technical Manual BCIS-21: Specification for non-spillable certification valve), and/or relevant BCI, DIN, BS and IEC standards.
- Lead acid batteries shall be installed and maintained in accordance with IEEE Std. 937-2019.
- The manufacturer's requirements for storage, shipping, installation, and safety shall be observed.

- Lead acid batteries shall use 2 V cells and battery capacity is to be designed according to its technology (VLA, VRLA, sealed in Gel, etc.)
- Battery terminal shall be provided with covers.
- Batteries shall be provided with micro porous vent plugs with floats.
- Charging instructions shall be provided along with the batteries.
- Suitable carrying handle shall be provided.
- A suitable battery rack with interconnections & end connector shall be provided to suitably house the batteries in the bank.
- The batteries shall be rated for operating in the environmental conditions in the State of Qatar.
- The self-discharge of batteries shall be less than 3% per month at 20°C and less than 6% per month at 30°C.
- The charge efficiency shall be more than 90%.
- The batteries shall have appropriate ventilation.

The battery characteristics are given in the following table.

Table 5 – Technical Requirements of the Battery

No	Parameter	Requirement
1	Battery technology	Deep-cycle Lead-acid battery/Lithium-ion battery
2	Rate of discharge	C/10 or C/20
3	Battery efficiency	≥ 90%
4	Operation temperature	-5 °C to 55°C
5	Self-discharge	less than 3% per month
6	Batteries enclosure IP rating	based on battery and installation
7	Product warranty against manufacturing defects	≥ 5 years
8	Workmanship warranty	Minimum 5 years
9	Quality and safety certifications	BCIS-21:2020 (specification for non-spillable certification valve)
		IEC 61427-1
		IEC 60896-11,21,22
		Other applicable BCI, DIN, BS, and IEC standards

More energy storage solutions further than batteries have been studied and some products are becoming available, particularly flywheels. Compressed-air storage are promising too but few products are being marketed so far.

4.8 Balance of Systems (BoS)

All BoS equipment shall be qualified according to International Standards listed in Par. 1.3.

4.8.1 Array Combiner Box

- PV string/array combiner boxes shall comply with IEC 61439-1/2.

- string/array combiner boxes shall have high quality suitable capacity metal oxide varistors (MOVs)/surge arrestors, and suitable reverse blocking diodes. The string/array combiner boxes shall have suitable arrangement monitoring and disconnection for each of the groups.
- String/array combiner boxes shall incorporate DC string circuit breakers, DC array disconnect switch, lightening and over voltage protectors, screw type terminal strips, strain-relief cable glands, and any other required protection equipment. The SPD should be Type 2 as per IEC 60364-5-53.
- Not more than two strings can be connected in parallel to a single input of SCB/AJB. One spare input terminal along with connector shall be provided for each SCB/AJB. Every SCB/AJB input shall be provided with fuses on both positive and negative side.

4.8.2 DC Distribution Box

- The DC distribution box shall receive the DC output from the array field with a measurement meter for voltage, current and power from different combiner boxes to check any failure in the array field.
- The DC distribution box shall be dust & vermin proof. The bus bars should be made of copper of desired size. Suitable capacity circuit breaker to be provided for controlling the DC power cable feeding the Inverter along with necessary surge arrestors.
- The DC distribution box shall incorporate DC disconnect switch, lightening surge protectors, any other protection equipment, screw type terminal strips and strain-relief cable glands.

4.8.3 AC Distribution Box

- The AC distribution box shall control the AC power from the Inverter and should have necessary surge arrestors. The interconnection from the AC distribution box to the mains at the LV bus bar shall be carried out. All equipment, sensors, and measurement devices shall be installed in the AC distribution box. An AC distribution box shall be provided at the cable terminating point emanating from the Inverter for interconnection control of the dedicated electrical loads.
- The AC distribution box shall incorporate AC circuit breakers, surge protective devices, any other protection equipment, plant energy meter, screw type terminal strips and strain-relief cable glands.
- The AC distribution box shall be wall mounted inside the control room.

4.8.4 Cables & Wires

- The DC wiring of the Standalone Solar PV System shall comply with IEC 62548 (7.3.7 Cables), IEC 60364-7-712 (712.52 Wiring system), and IEC 62930. The AC wiring system shall abide by the provisions of Kahramaa' s Low Voltage Electricity Wiring Code 2016" as well as any other applicable provisions applicable in the State of Qatar.
- All cable/wires shall be marked in a proper manner by good quality ferule or by other means so that the cable can be easily identified. All cable schedules/layout drawings shall be approved from the purchaser prior to installation. All cable tests and measurement methods should confirm to IEC 60189-3.
- All DC and AC cables shall be terminated using suitable crimped cable lugs/sockets and screw type terminal strips. No soldered cable termination shall be accepted.

- Only terminal cable joints shall be accepted. No cable joint to join two cable ends shall be accepted.
- Conduits/concealed cable trays shall be provided for all DC cabling on the ground/roof. Conduits/concealed cable trays shall be adequately secured onto the ground/roof.
- The DC and AC cables of adequate electrical voltage and current ratings shall be also rated for in conduit wet and outdoor use.
- The DC and AC cable size shall be selected to maintain losses within specified limits over the entire lengths of the cables. The maximum voltage drop should be limited to 1%.
- DC cables from array combiner box to DC distribution box shall be laid inside a cable duct where available or secured with conduits/concealed cable trays where duct is not available.
- DC and AC cabling between Inverter and distribution boxes shall be secured with conduits/concealed cable trays.
- All cable conduits shall be GI/ high density Polyethylene type or rigid PVC.
- All cable trays shall be powder coated steel or GI or equivalent.
- Multi strand, annealed high conductivity copper conductor should be used.
- PVC type ‘A’ pressure extruded insulation should be used.
- Overall PVC insulation for UV protection should be implemented.
- Armoured cable for underground laying should be used.
- All cables shall conform to Kahramaa Wiring Code 2016 and the relevant international standards.
- All electrical cables/wires inside the building to be fixed in accordance with specifications for electrical works.
- Proper laying of cables shall be ensured in appropriate cable trays, pipes / trenches as per site requirement.
- AC supply cables shall be terminated at the distribution boxes.
- For laying/termination of cables, latest international codes & standards shall be followed.

The following table provides recommendations relevant to the BoS components.

Table 6 – Technical Requirements for BoS Components

No	Component	Requirement
1	String/array junction boxes	IP65, Protection Class II
2	Surge protective devices	Type 2, DC as per IEC 60364-5-53
3	Enclosures for Inverters and Charge Controllers	IP65 (Outdoor) / IP20 (Indoor)
4	PV Module/string/string combiner box interconnects	MC4 compatible, DC 1500 V rated
5	Inverters	IP65 (Outdoor) / IP20 (Indoor)
6	The DC/AC distribution boxes	IP65 (Outdoor) / IP20 (Indoor)
7	The data acquisition systems	IP65 (Outdoor) / IP20 (Indoor)
8	All DC and AC cables, conduits, cable trays, hardware	Relevant International Standards

No	Component	Requirement
9	Earthing System	TN-S earthing system in accordance with IEC 60363
10	PV Array support structure	Relevant International Standards
11	Parts and Workmanship warranty	Minimum 10 years
12	Service warranty	Minimum 10 years

4.9 Auxiliary Systems

4.9.1 Fire Extinguishers

- A firefighting system for the proposed PV System shall consist of:
  - Portable fire extinguishers in the control room for fire caused by electrical short circuits.
- The installation of fire extinguishers shall confirm to Qatar's Civil Defence regulations and international standards. Fire extinguishers shall be provided in the control room as well as on the site where the PV Arrays have been installed.

4.9.2 Lightning and Surge Protections

- In accordance with IEC 62305, the PV System shall be always protected against the effects of overvoltage by means of suitable measures aimed to avoid or mitigate the occurrence of overvoltage (e.g. metallic protections, shields) and/or to suppress them by proper devices as SPDs. The need for SPDs (Surge protective devices) should be assessed according to IEC 62305 (all parts) and appropriate protective measures implemented. IEC 62305-4 can provide a methodology for protection of electrical and electronic systems in a lightning environment.
- In case of a PV System installed on a building where an external Lightning Protection System (LPS) is present the PV System shall not reduce the effectiveness of the LPS and shall be properly integrated in compliance with IEC 62305-3.
- Normally the presence of a new PV System does not change the lightning risk of a building and therefore if the building has not an external LPS this measure will not be required after the installation of the PV System. In this case, and also in case of a free-standing PV System, overvoltage protection may still be required to protect the PV Array, the Inverter and all parts of the installation.
- However, if the physical characteristics or prominence of the building do change significantly due to the installation of the PV System, it is recommended that the need for a lightning protection system be assessed in accordance with IEC 62305-2 and, if required, it should be installed in compliance with IEC 62305-3. A lightning and surge protection system shall comprise of air terminations, down conductors, test links, earth electrode, surge protective devices, etc.

4.9.3 Earthing Protection

- Earthing protection system shall comply with IEC 62548, 7.4.2 Earthing and bonding arrangements and IEC 60364-7-712 - Earthing requirements.
- PV Array structures, DC equipment, Inverter, AC equipment, and distribution wiring shall be earthed as required.

- All metal casing/shielding of the plant shall be thoroughly grounded. In addition, the lightning arrester/masts should also be provided inside the array field.
- Equipment grounding (Earthing) shall connect all non-current carrying metal receptacles, electrical boxes, and PV Module mounting structures in one long run. The grounding wire should not be switched, fused, or interrupted.
- The complete earthing system shall be electrically connected to provide return to earth from all equipment independent of mechanical connection.
- Earthing system design should be as per best practice and standards in Table 1.
- Earth pits shall ensure the electrodes are embedded below permanent moisture. For each earth pit, a necessary test point shall be provided.
- The equipment grounding wire shall be connected to earth strip by proper fixing arrangement.
- Necessary provisions shall be made for bolted isolating joints of each earthing pit for periodic checking of earth resistance.
- Earth leakage current and earthing resistance should be tested in presence of the representative of Kahramaa after earthing by a calibrated earth tester, once the system is in operation. As for the acceptance criteria, useful references are
  - less than 30 mA for earth leakage, and
  - less than 5 Ohm for earthing resistance.

  The Consultants/Contractors may verify these acceptance criteria with reference to the actual design and environmental conditions in the site of the installation.

4.10 Safety issues

The provisions of one or more of the following shall apply to the protection against the safety issues listed below.

- Protection against electric shock
  - IEC 60364-4-41 Low-voltage electrical installations – Protection for safety – Protection against electrical shocks
  - IEC 62548, 6.2 Protection against electrical shock

  Each standard requires one or more of the following protections: double or reinforced insulation, separated/safety extra-low voltage (SELV) or protected extra-low voltage (PELV).

- Protection against thermal effects
  - IEC 60364-4-42 Low-voltage electrical installations – Part 4-42: Protection for safety – Protection against thermal effects
  - IEC 62548, 6.3 Protection against thermal effects

  Each standard requires protection from insulation faults within the system.

- Protection against overcurrent
  - IEC 60364-4-43 Low-voltage electrical installations – Protection for safety – Protection against overcurrent
  - IEC 62548, 6.5 Protection against overcurrent

  All fuses and circuit breakers, including fuse holders and circuit breaker panels, shall be appropriate for use in the system and each of these two shall comply with its requirements. Fuses shall comply with IEC 62548 (7.3.5 Fuses) and/or

IEC 60364-7-712 (712.533 Devices for protection against overcurrent); circuit breakers shall comply with IEC 62548 (7.3.4 Circuit Breakers) and/or IEC 60364-7-712 (712.533 Devices for protection against overcurrent).

- Protection against overvoltage
  - IEC 60364-4-43 Low-voltage electrical installations – Protection for safety – Protection against voltage disturbances and electromagnetic disturbances
  - IEC 62548, 6.6.2 Protection against overvoltage

- IEC TR 63226 – Managing fire risk related to photovoltaic (PV) systems on buildings is a Technical Report intended for use as guidance for reducing fire risks in general and for site-specific needs for buildings with PV Systems.

4.11 Commissioning

Commissioning shall occur before the user can operate a Standalone Solar PV System.

4.11.1 Preassembled Standalone Solar PV Systems

The commissioning of preassembled systems (e.g.: solar powered outdoor lighting unit) shall be according to guidelines defined by the equipment manufacturer and provided with the equipment documentation.

4.11.2 Custom Standalone Solar PV Systems

The following guidelines describes the commissioning of the Standalone Solar PV Systems designed and constructed by the competent persons.

Also, the commissioning process can take advantage of guidelines and checklists defined for the commissioning of the Small-scale Solar PV Systems connected to the distribution network of Kahramaa.

4.11.2.1 Testing of the Solar PV generator (DC side).

The “Off-line tests” applicable to the Small-scale Solar PV Systems that connect to the Kahramaa distribution network are applicable to test the Solar PV generator of a Standalone Solar PV System. The Solar PV generator includes PV strings, PV Arrays, junction boxes, cable connections, equipment, and devices in the DC side of the system.

The guidelines are described in the Chapter 7 “Off-line Tests” of the document “*CS-CSI-P3-G2 Inspection and Testing Guidelines for Solar PV Systems Connected to LV and MV Network*”, and the details of these off-line tests are specified in the paragraphs here mentioned for proper reference.

Table 7 – "GS-CSI-P3-G2 Inspection and Testing Guidelines for Solar PV Systems Connected to LV and MV Network" Tests applicable to Standalone PV Systems

"CS-CSI-P3-G2 Inspection and Testing Guidelines for Solar PV Systems Connected to LV and MV Network" Tests applicable to Standalone PV Systems	
Chapter / Section	**Title of the Chapter or Section**
7.4	**DC System**
7.4.1	DC system – General Verifications
7.4.2	DC system – Verification of the Protection against Electric Shock
7.4.3	DC system – Verification of the Protection against the Effects of Insulation Faults
7.4.4	DC system –Verification of the Protection against Overcurrent
7.4.5	DC system – Verification of Earthing and Bonding Arrangements
7.4.6	DC System – Verification of the Protection against the effects of Lightning and Overvoltage
7.4.7	DC system – Verification of the selection and erection of electrical equipment
7.4.8	Checklist for DC System Verification
7.5	**Labelling and Fire Protection**
7.5.1	Labelling and identification
7.5.2	Fire Protection Verification
7.5.3	Verification of the Special Requirements for Households
7.6	**Basic Tests**
7.6.1	Continuity Test of Protective Earthing and Equipotential Bonding Conductors
7.6.2	PV string Polarity Test
7.6.3	PV string Combiner Box Test
7.6.4	Open Circuit Voltage Measurement of PV Strings
7.6.5	Current measurement of PV strings
7.6.6	Functional Tests
7.6.7	PV Array Insulation Resistance Test
7.6.8	Checklist for the PV Array Tests
7.6.9	Earth Resistance of the PV System
7.6.10	Infrared Camera Inspection for Inverters and Circuit Breakers
7.7	**Additional Tests**
7.7.1	String I-V curve Measurement
7.7.2	PV Array Infrared Camera Inspection Procedure
7.7.3	Voltage to Ground – Resistive Ground Systems
7.7.4	Blocking Diode Test
7.7.5	PV Array – Wet Insulation Resistance Test
7.7.6	Shade Evaluation

4.11.2.2 Testing of other components of the Standalone Solar PV System or parts of the installation

Except for those parts that can be tested based on provisions given in Section 4.11.2.1, other components of the Standalone Solar PV System or parts of the installation shall be tested according to Kahramaa' s Low Voltage Electricity Wiring Code 2016, and following guidelines and specifications set forth by the equipment manufacturers and/or the appointed Consultants/Contractors. Particularly, Consultants/Contractors shall carry out the following additional activities whenever appropriate and necessary:

- Wiring and protection equipment insulation resistance test
- Thermography of main electrical connections.
- Loop resistance test for the wirings and protection system

4.11.2.3 Final provisions

Consultants/Contractors shall successfully complete test and commissioning activities before the Standalone Solar PV System starts operation. Consultants/Contractors shall prepare in advance a proper plan describing the test and commissioning activities, considering the following recommendations.

- Test and commissioning shall include any additional components supplied/installed further than the standalone solar PV System e.g., water pumping, purification, desalination, and loads in residential commercial industrial premises. Consultant/Contractor shall verify that the manufacturers supply the equipment along with the procedures for test and commissioning or clearly indicate the international Standards defining the applicable procedures.
- If additional equipment and components were present in the site before the standalone Solar PV System, the Consultant/Contractor shall agree with the owner the extent of his commitment (i.e., battery limits) and define the test and commissioning plan accordingly.
- The plan shall clearly identify and describe all test and commissioning activities included within the said battery limits. A separate section shall highlight all test and commissioning activities pertaining to the safety of the installation.

5 System Documentation

Consultant/Contractor shall assess the actual needs of his Client and reflect these needs in a detailed Technical Specification that may explain pros and cons of different options and highlight the expected benefits for the Client or user who use the standalone Solar PV System. More detailed requirements of the system documentation are provided in the following.

5.1 Final Design

The Consultant/Contractor shall prepare a complete design with the technical characteristics and description of the Off-grid Solar PV System. The documentation shall be submitted to the owner and to the company that will take care of the maintenance.

For systems supplied off-the shelf, like street lighting or containerised desalination systems, a product brochure and a description of the installation are enough.

For systems with several strings of PV Modules, mounting structure, especially for rooftop installations, a proper **Design Package** shall be prepared as recommended below. However, Consultant/Contractor may adopt a different structure, provided there is a clear separation between characteristics from equipment manufacturers, and original information elaborated when designing the complete Standalone PV System.

The **Cover Page** of the Design Package shall include the following information:

a) Project name
b) Rated (nameplate) system power (kW DC and kVA AC)
c) PV Modules
d) Inverters, Battery Charge Controllers and batteries, or other storage means.
e) Installation date
f) Commissioning date
g) Consumer name
h) Site address

The Design package shall include the following minimum system information.

The structure and content of the Design Package will depend on the capacity of the Standalone PV System.

- Systems based on Inverters with built-in Charge Controller, or system up to 11 kW,
- Systems above 11 kW.

5.1.1 Design Package for systems based on Inverters with built-in Battery Charge Controller or systems up to 11 kW

Wiring Diagram and Standalone PV System Characteristics

A single line wiring diagram in a suitable and readable format. Further details can be presented as annotations to the single line wiring diagram. For larger systems this information may be presented complementary presented in table form.

Wiring diagram and system characteristics shall include the following information.

Array – General Characteristics

a) PV Module type(s).

b) Total number of PV Modules.
c) Number of strings.
d) Number of PV Modules per string.
e) Identify which strings connect to which Inverter.

Where an array is split into sub-arrays, the wiring diagram shall show the array – sub-array design and include all the above information for each sub-array.

PV string information

a) String cable characteristics – size and type.
b) String overcurrent protective device specifications (where fitted) – type and voltage/current ratings.
c) Blocking diode type (if relevant).

PV Array electrical details

a) Array main cable characteristics: Size, type, manufacturer and model.
b) Array junction boxes / combiner boxes: Locations, manufacturer, model and internal electric diagram.
c) DC switch disconnector: Location and rating (voltage/current), manufacturer and model.
d) Array overcurrent protective devices: Type, location, rating (voltage/current), manufacturer and model.
e) Other arrays electronic protective circuitry (such as arc fault detection), if applicable: Type, location, rating, manufacturers and models.

AC system

a) AC isolator location: Type, rating, manufacturer and model.
b) AC overcurrent protective device: Location, type, rating, manufacturer and model.
c) Residual current (where fitted): Device location, type and rating.

Earthing and overvoltage protection

a) Details of all earth / bonding conductors – size and type. Including details of array frame equipotential bonding cable, where fitted.
b) Details of any connections to an existing Lightning Protection System (LPS).
c) Details of any surge protection device installed (both on AC and DC lines) to include location, type and rating.

Planimetry and String layout

Planimetry of the PV Array shall include information about tilt and orientation. Possible sources of shading shall be clearly indicated.

A layout drawing of the PV System showing how the array is split and connected into strings shall be provided for systems with three or more strings.

This is particularly useful for finding faults in larger systems and on building-mounted arrays where access to the rear of the modules is difficult.

Datasheets

a) PV Module datasheet for all types of modules used in the PV System
b) Inverter datasheet for all types of Inverters used in the PV System.
c) Charge controller and batteries, or other storage means.
d) Any other significant system components.

Mechanical design

A data sheet for the array mounting system shall be provided. If the mounting structure was custom engineered, the relevant documentation should be included.

Emergency systems

Documentation of any emergency systems associated with the PV System (fire alarms, smoke alarms, etc.). This information shall include both operation and design details.

Estimation of the yearly energy production

An estimate of the yearly energy production shall be calculated using solar energy simulation software like PVsyst or SAM. This is especially requested for Standalone PV Systems designed to supply large villas of commercial/industrial buildings

5.1.2 Design Package for systems above 11 kW

For systems above 11 kW, the Design Package shall include the following minimum documents and information.

Design Report

Structure and minimum content of the Design Report recommended in the following.

Chapter 1 – Foreword (or Introductory section, or Preface, etc.)

- Type of solar system (rooftop, ground-mounted, façade, etc.), integration if relevant (BAPV, BIPV, etc.), fixed mounting or tracking, technology (monocrystalline, polycrystalline, thin-film, etc.)
- Short description of the project's purpose, also referring to the benefits for the client, for the environment, for the electric system, for the Nation, etc.
- System designer (Consultant). Information for all bodies responsible for the design of the system. Where more than one company has responsibility for the system's design, the following information should be provided for all companies, along with a description of their role in the project.
  a) company.
  b) contact person.
  c) postal address, telephone number and e-mail address.
- System installer (Contractor). Information for all bodies responsible for the installation of the system. Where more than one company has responsibility for the system’s installation, the following information should be provided for all companies, together with a description of their role in the project.
  a) company.

b) contact person.
c) postal address, telephone number and e-mail address.

Chapter 2 – Input data

- Definitions (recommended)
- Laws and standards applicable (the most relevant ones)
- Solar and environmental data on the site (monthly averages of direct and diffuse solar radiation, wind speed, average and maximum temperatures, etc.)
- Geological and environmental constraints (if any) as the type of soil, inclination, need of stabilisation or other treatment, shading, presence of vegetation, animals, etc.)

Chapter 3 – Characteristics of the main devices and equipment

- PV Modules (Manufacturer, model, technology, type of PV cells, PN, Vm, Im, Voc, Isc, Temperature coefficients, NOCT, dimensions and weight, certifications, etc.)
- DC combiner boxes – if present – (Manufacturer, model, No. of inputs, protection on inputs, switch/disconnector, PV string monitoring if any, IP enclosure, dimensions, weight, certifications, etc.)
- Inverters (manufacturer, model, Pn, Max input current, Max input voltage, MPPT range, output voltage and frequency range, Max temperature, IP enclosure, dimensions, weight, certifications, etc.)
- Battery Charge Controllers (manufacturer, model, rated voltage, rated charge current, load current, input voltage range, Max temperature, IP enclosure/rating, weight, certifications, etc.) and batteries (manufacturer, technology, model, nominal capacity Ah, nominal cell voltage, self-discharge, Max temperature, IP enclosure/rating, weight, certifications, etc.), or other storage means
- Monitoring system – if any – (manufacturer, model, solar and meteorological inputs, DC inputs, AC inputs, data line exchange, storage, data display, certifications, etc.)

Chapter 4 – System architecture and dimensioning

- DC and AC capacity and how it is obtained from PV Modules and Inverters
- System architecture from PV Modules to distribution board (i.e., a block diagram with PV Modules, Inverters, main switches and protections, etc.)
- Characteristics of PV strings and array(s) (V_m, I_m, V_{OC}, I_{SC}, inclination(s), orientation(s))
- Verification of compliance for PV strings/array(s) and Inverters (MPPT range, maximum voltages, maximum currents, etc.)
- If present, description of the storage system (battery and battery charger, protection, installation, safety considerations and provisions, etc.)

Chapter 5 – DC section

- Verification of compliance for DC cables (current, voltage drops)
- Measures to prevent overcurrent in parallel PV strings

Chapter 6 – AC section

- Measures to prevent electric shocks from direct contacts (class II insulations, tubes and channels, etc.)
- Measures to prevent electric shocks from indirect contacts (earthing, RCDs, etc.)
- Characteristics of the main AC devices (Manufacturer, model, type, No. of poles, aux contacts, nominal current, short-circuit current, protection characteristics, etc.)
- AC calculations (verification of compliance for AC devices and cables)

Chapter 7 – Civil and mechanical installation

- Description of the mounting structures
- Design philosophy
- Structural calculations and analysis
- Civil drawings

Chapter 8 – Performance calculation

- Calculation of the solar radiation on the PV System
- Energy Yield (monthly and yearly)
- CO_2 saved

Wiring Diagrams for systems above 11 kW

In addition to the diagrams specified for systems up to 11 kW, multiple line wiring diagrams in a suitable and readable format.

5.2 System Manual

A system manual shall be supplied with each standalone solar PV System.

The system manual shall be submitted to the owner in at least two copies (one copy for the owner, one copy for the company in charge of the maintenance of the Solar PV System).

The system manual shall include the following:

- A complete equipment list for the system alongside the technical characteristics and datasheets for each component of the designed Standalone PV System should be submitted according to the Form PW-S2/F1.
- Product quality certificates, from a certified testing laboratory, and manufacturer warranty certificates, for: PV Modules, Inverters, Charge Controllers, batteries, and any other devices used in the Standalone Solar PV System.
- A summary of the system characteristics (including electrical protection equipment), load characteristics, and monthly system performance.
- Electrical line diagrams for the system.
- System operation procedures.
- Emergency procedures.
- Maintenance procedures.
- Copies of engineering calculations and drawings.
- Installation and O&M manuals.

The maintenance of standalone Solar PV Systems and other equipment is based on manufacturers' instructions supplied with each system component (PV Modules, Charge Controllers, Inverters, batteries, etc.). Consultants/Contractors shall collect these instructions with the purpose to compile a comprehensive maintenance manual of the standalone Solar PV System.

ANNEX A

Annex A contains examples of standalone solar powered water supply systems.

Disclaimer

The products presented in this Annex are illustrative of the potential applications of the solar powered water supply systems. The manufacturers are the solely responsible for the specifications and performance of the products and for the compliance with any applicable local and international standards. Consultants/Contractors are the solely responsible for the selection and implementation of the water supply systems most appropriate to fulfil the users' requirements.

The Solar-Powered Water Pumping Systems operates on power generated using solar PV (photovoltaic) system. The photovoltaic array converts the solar energy into electricity, which is used for running the motor pump set. The pumping system draws water from the open well, bore well, stream, pond, canal etc. Many water pumping manufactures have included in their portfolio complete systems powered by Solar PV Modules. These standalone systems can provide water for irrigation in agriculture as well as for the gardens: because they are portable and do not need power from mains, they can be moved from one site to another site depending on water availability.

Below we report a synthetic description of a solar-powered water pumping system.

- The system mainly consists of a series of PV Modules to supply solar energy to the pump, which can be either submerged or above the ground. Other components are the solar Inverter, to convert the DC output of the PV Modules to AC to the pump and any water storage tanks.
- Solar-water pumping systems without storage shall comply with IEC 62253.
- Usage scenarios can be small-scale irrigation, livestock watering and water supply in rural areas not reached by the main network.
- Solar water pumping systems are durable and reliable, they have the advantage of having no operational costs, low maintenance levels (only occasional cleaning of PV Modules), low life cycle costs due to the reduced payback period and, obviously, zero carbon emission. On the other hand, they have high initial capital costs. However, component prices are dropping, and investment payback is quick.

The Figure 2 show a general scheme of a water pumping system. The water tank is optional as the pump may send the water directly to the final use. A controller can be added to operate the system. A battery system may be added to ensure enough power to supply the pump in the night.

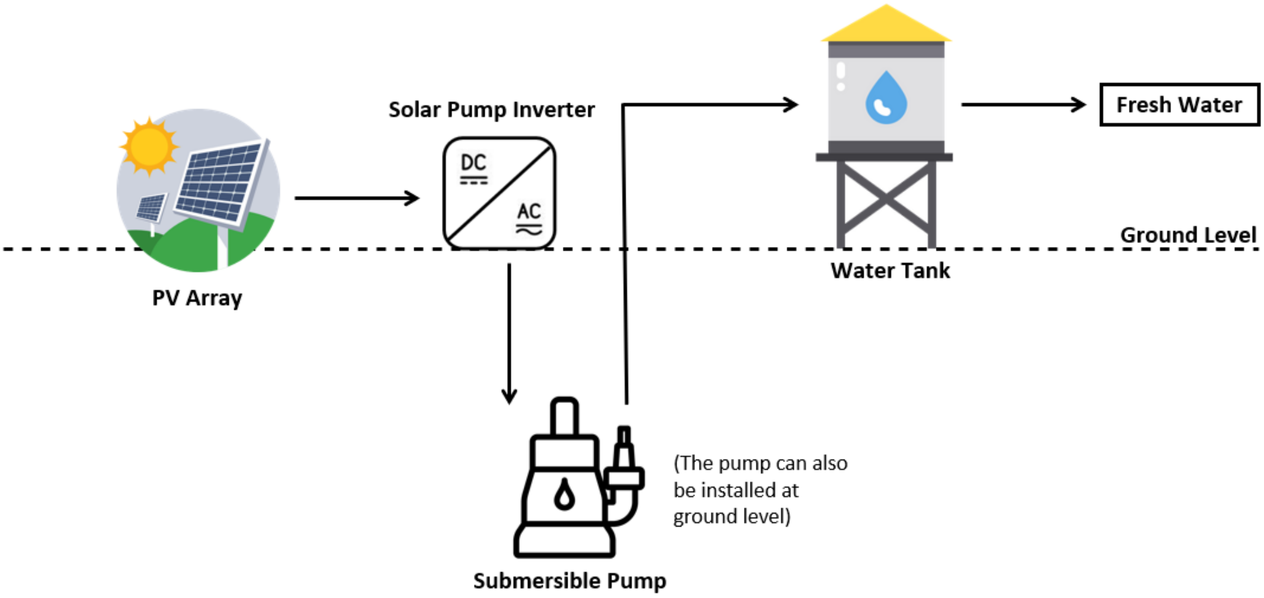

Figure 2 – Schematic of a solar-powered water pumping system

Possible applications of solar powered water pumping in an isolated residential environment:

- provide water for human consumption
- water your garden, lawn, plot, or small holding
- ensure crystal clear swimming pool
- run water feature

Additional applications and features available to farmers

- submerged and surface pumps to water plots in the farm area
- ensure drinking water for livestock
- water storage, battery storage or hybrid PV/diesel systems to ensure full time operation
- add a monitor and management system to supervise all remote pumping equipment

Figure 3 – The combo figure shows a pool pumping system installed in Bahrain
(Source: Lorentz – https://www.lorentz.de/)

Solar water solutions offer smarter and more viable ways to deliver reliable water supply. After the initial investment, operating costs are extremely low, this keeps solar water pumping economically sustainable and viable for long-term operation in remote sites, for several consumer's categories and applications including agriculture, fisheries, commercial and similar small business enterprises.

- Drip and sprinkler irrigation: smaller pumps with an integrated solar Inverter, drippers or emitters are most water-efficient and work with both pressurised and gravity systems
- Flood and pivot irrigation: these require a larger pump with an external solar Inverter.
- Livestock watering: Pump water either directly to the watering station or to a tank
- Pumping to tank: solar water pumping to a holding tank while the sun is shining, from where water is released either pressurised or by gravity feed

The Figure 4 shows a comprehensive representation of these potential applications of solar pumping.

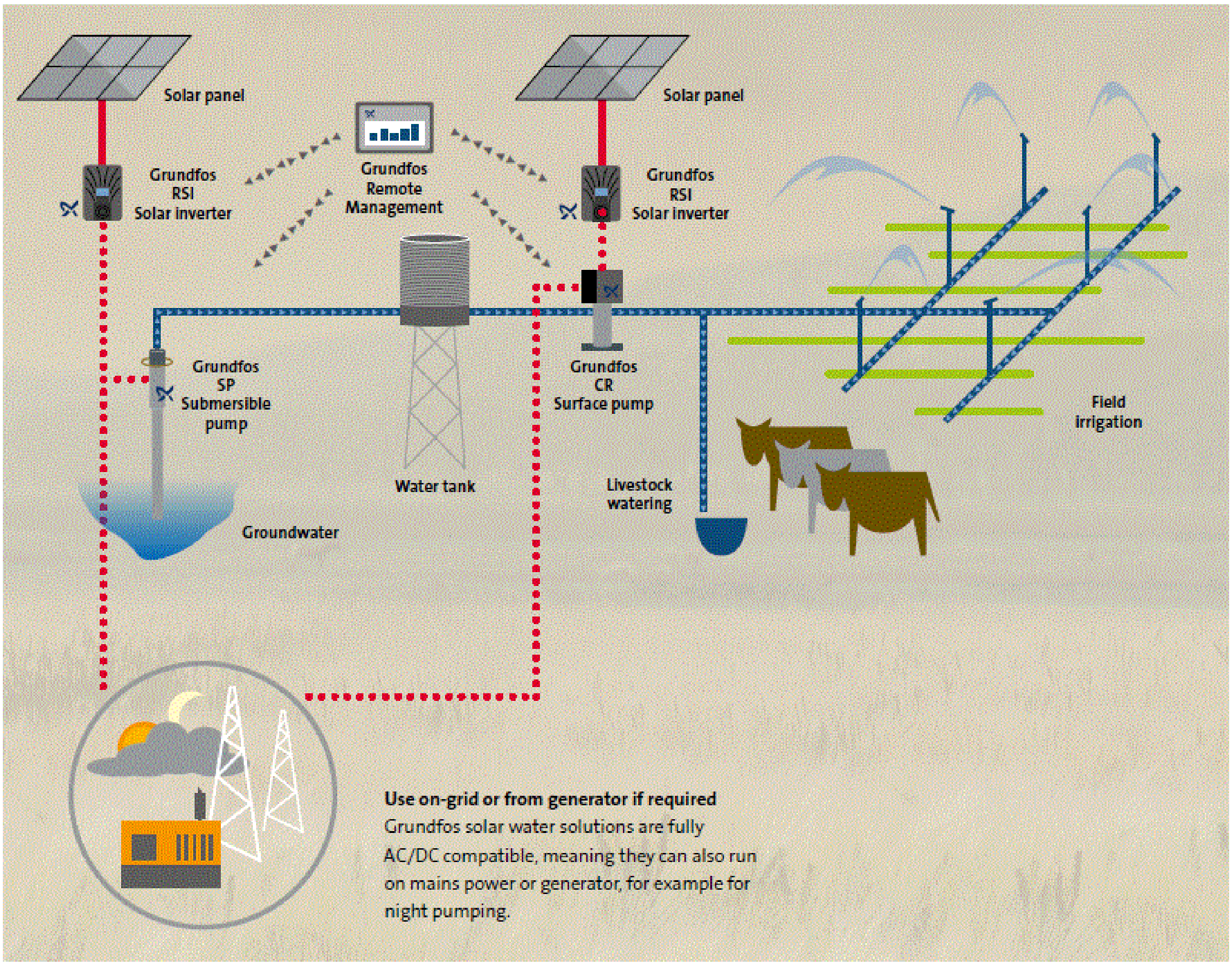

Figure 4 – Complete solar water supply solutions for crop irrigation and livestock watering (Source: "SOLAR-POWERED WATER SUPPLY" https://www.grundfos.com/)

Solar water pumping solutions are particularly supplied to developing regions to increase the availability of water and improve the performance of farm activities in agriculture and livestock.

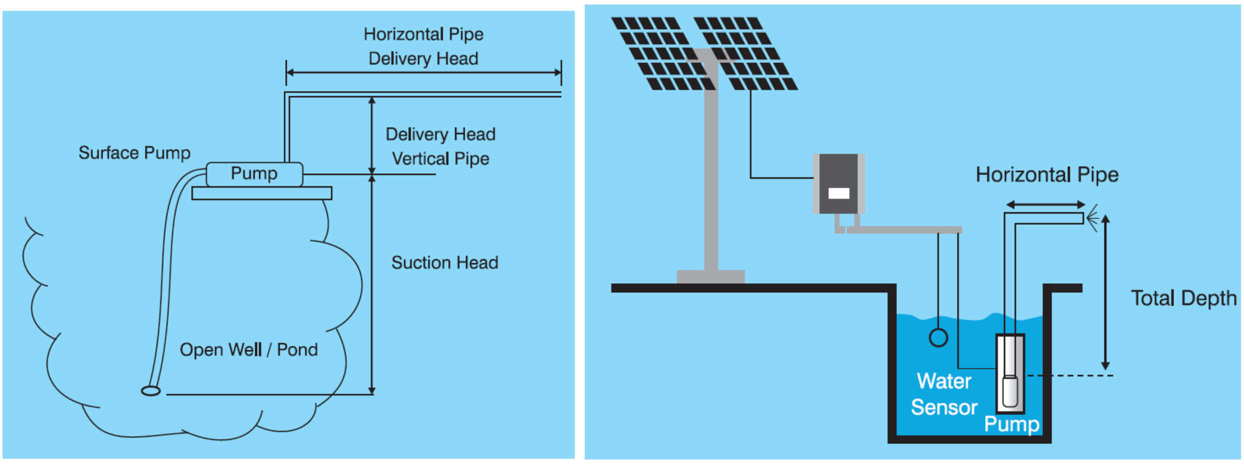

Figure 5 – Schematic of solar pumping systems with surface (left) or submerged (right) pumps (Source: "TATA POWER Solar Pumps" https://www.tatapowersolar.com/)

B. Solar-powered water treatment systems: desalination

Desalination aims at removing minerals and salts from saline water to produce freshwater for human use or irrigation. The process applied to seawater and brackish water with different performances criteria. It is normally considered that salinity below 500 ppm is suitable as drinking water. Basically, a complete desalination process includes 3 steps: pumping water (from sea, estuaries, or saline aquifers), pre-treatment (filtration, chemical addition), desalination. A post treatment step can be added in some cases, adding few minerals. The more common technologies to produce freshwater with desalination technologies are: Reverse Osmosis, Multi-stage Flash Process, Multi Effect distillation. These as well as other processes are described extensively in the literature.

Below we report a synthetic description of solar-powered water treatment systems for desalination.

- Small-scale water treatment systems capable of producing clean fresh water associated with solar PV applications with low capital cost, easy operation and less need of maintenance. The PV-powered desalination technology is an excellent choice to provide water for small to medium communities located in isolated areas with high availability of both solar radiation and saltwater.
- International standards are available to specify requirements and performance applicable to solar-powered water treatment systems, particularly standards on water treatment and water quality.
    - ISO 22519:2019 – Purified Water and Water For Injection pre-treatment and production systems. This document specifies design, materials selection, construction, and operation of Purified Water and Water For Injection pre-treatment and membrane-based production systems.
    - ISO 20468:2018 – Guidelines for performance evaluation of treatment technologies for water reuse systems. This document provides typical parameters of water quality and treatment efficiency of water treatment systems - ISO 20468:2018 Part 5: Membrane filtration
    - ISO 23044:2020: Guidelines for softening and desalination of industrial wastewater for reuse.

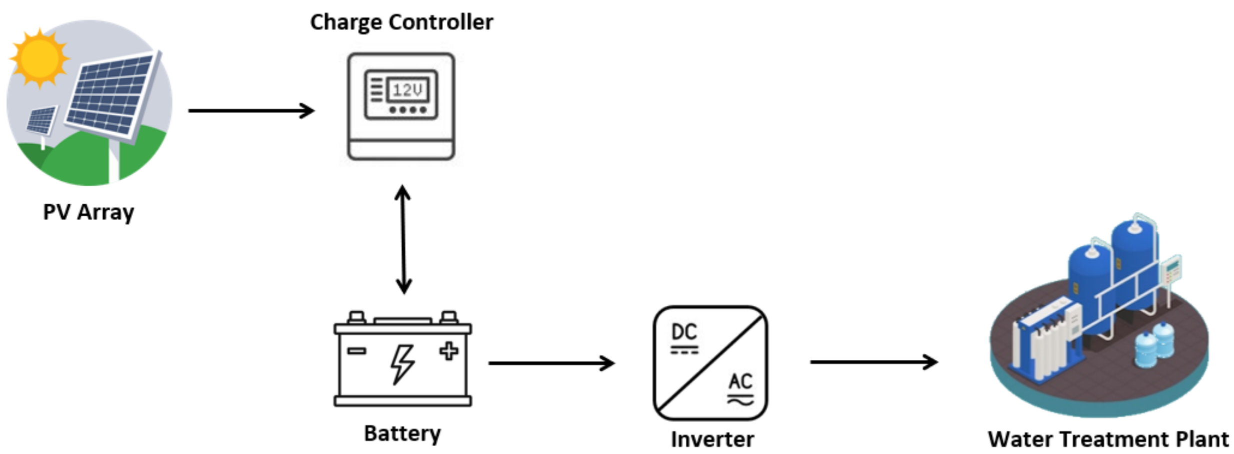

Figure 6 – Schematic of an off-grid solar PV-powered water treatment system

Examples of standalone solar PV powered systems that supply desalination equipment are available from various sources, for example the following scientific publication:

S. Gorjian et al.; Photovoltaic Solar Energy Conversion; Chapter 8 - Applications of solar PV Systems in desalination technologies; Academic Press, 2020.

Some products and applications are described in the following.

The source of water is a key element in the selection of the most appropriate water purification systems. In principle the possible water sources are three:

- Seawater is desalinated via a Reverse Osmosis system that removes salt, bacteria, viruses, and cysts without toxic chemical treatment.
- Brackish water is considered water with a higher salinity, typically from wells or boreholes. The process is as similar as desalination.
- Fresh Water is any non-saline source like river, lake or well water. Raw water is filtered through a high-technology hollow fibre membrane that remains the natural minerals in the water.

Independent water supply component and systems for human consumption in remote and isolated sites are nowadays available for small scale applications. For example, small scale systems can supply water to villas and similar private estates.

Figure 7 – Independent water supply for a large estate at Jumby Bay, a private island off the coast of Antigua (Source: https://aqsep.com/)

Solar powered desalination is a sustainable and resilient solution to provide clean and affordable water for rural communities and commercial & industrial businesses in case of scarcity of (clean) water. Solar powered, with or without battery, water desalination and purification systems can provide clean and potable water in remote areas and off-grid locations. These environmentally and economically sustainable systems can operate autonomously and can provide many years of service life.

Further than from seawater, these systems can use brackish water as a water source.

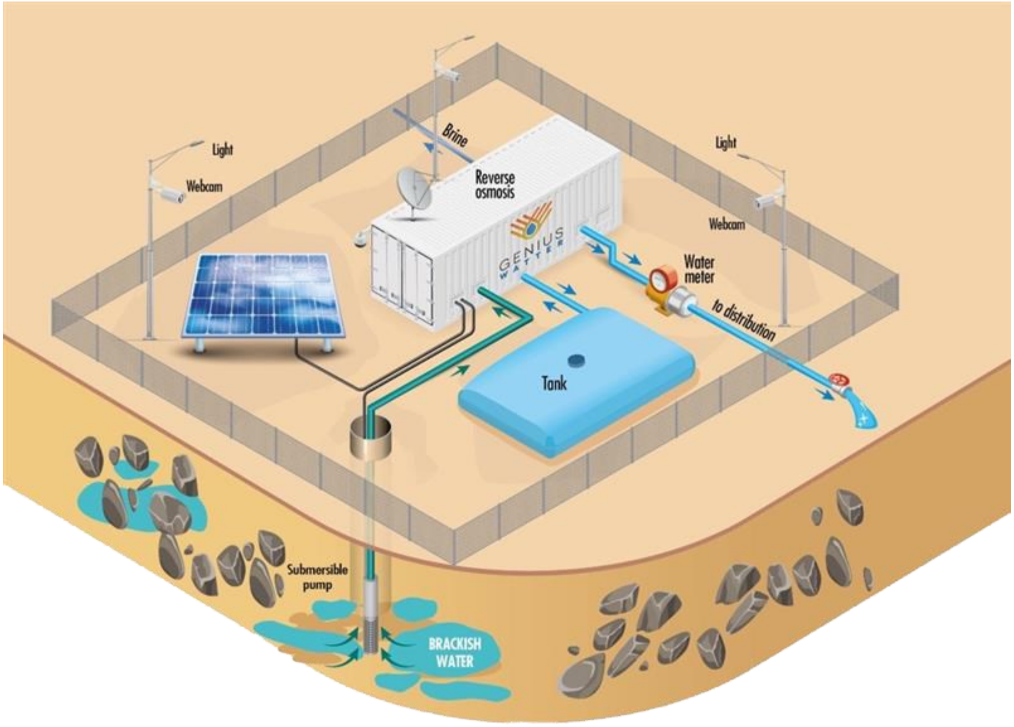

Figure 8 – Water desalination of seawater or brackish water with purification, to provide freshwater from 5 to 1000 m3/day (Source: https://www.geniuswatter.com/)

Containerized solutions are also available to produce clean water from seawater. These "plug & play" systems are quick to install and easy to maintain and they enable an independent water supply for any coastal location. These systems enable clean water for communities, resorts, industries, private properties, in addition to the most common applications, these containerised systems can be easily deployed in case of disaster relief and emergency response.

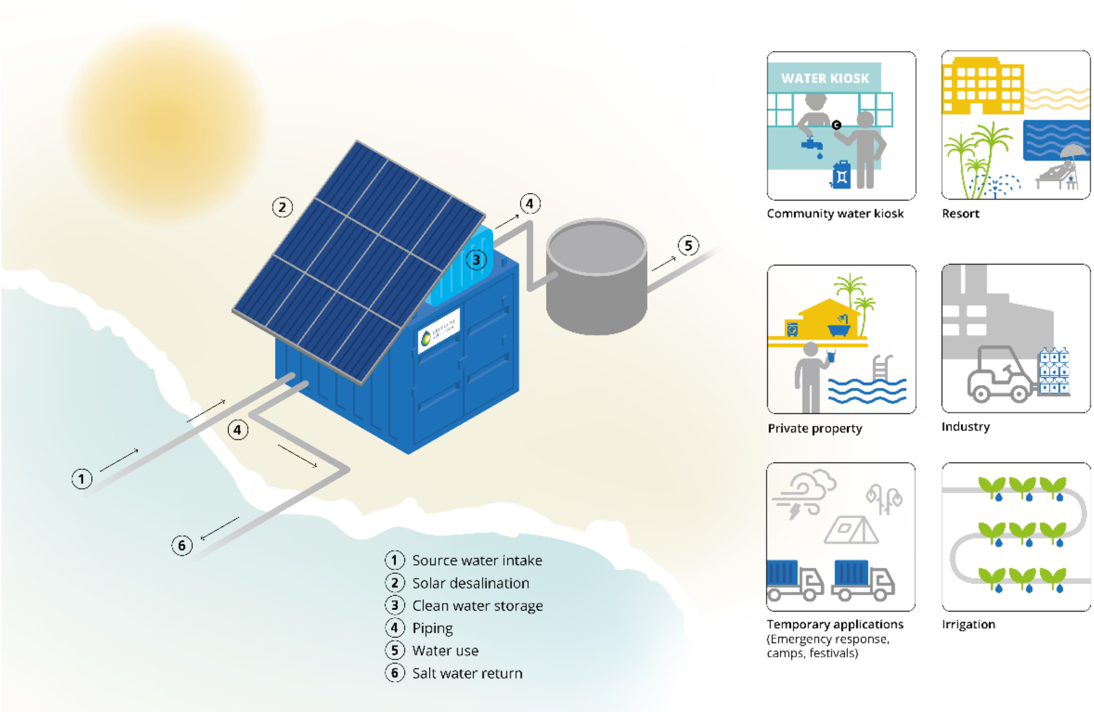

Figure 9 – Solar powered desalination (containerised) system of various sizes, allow from 5,300 to 40,000 litres/day of desalinated water (Source: https://www.elementalwatermakers.com/)

Figure 10 – Solar powered containerised system for brackish water (up to 18,000 ppm salt content) and seawater desalination (up to 42,000 ppm salt content). A system has been installed in a remote agriculture farm, near Al-Alin Desert, United Arab Emirates. (Source: https://www.trunzwatersystems.com/index.php)

ANNEX B

Annex B presents a generic single line diagram of a standalone solar PV System.

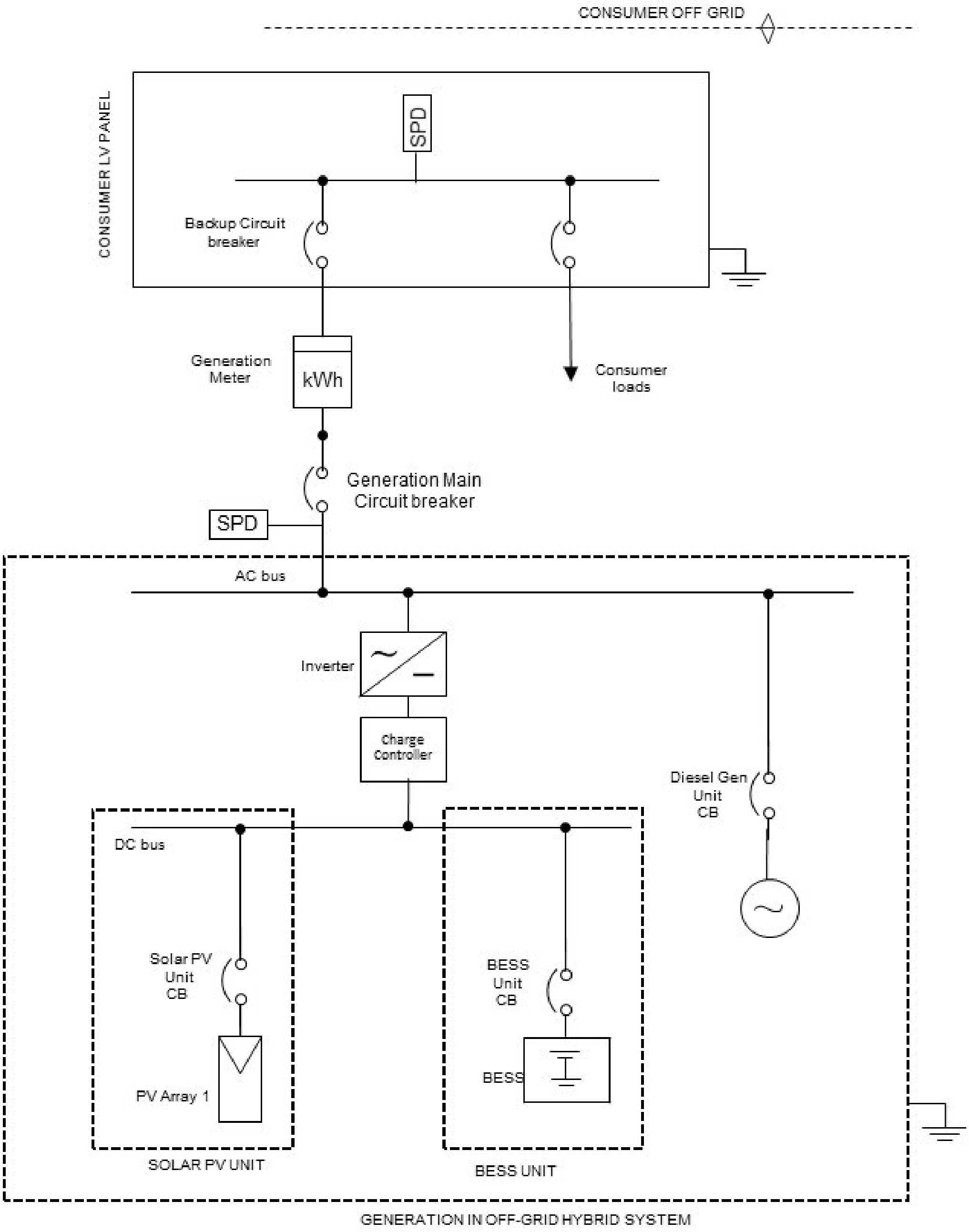

Figure 11 – Schematic representation of a standalone solar PV System